THE RV TAURI POPULATION

RICHARD STOTHERS

Goddard Institute for Space Studies
National Aeronautics and Space Administration
New York, New York

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Our understanding of the RV Tauri stars has come mainly from photometric and spectrographic studies based on several tabulations of these stars since 1921.[1–9] Although members of this group are too distant for accurate parallax determination, their absolute magnitudes are known through the discovery and identification of some in globular clusters.[5,10] It is the purpose of this paper to analyze the spatial distribution of the RV Tauri stars in the field and to compare properties of these stars with properties of similar stars found in globular clusters.

The data are taken mainly from the *General Catalogue of Variable Stars*[8] (*GCVS*), which lists 92 stars of this class based on criteria that are essentially those of Payne-Gaposchkin, Brenton, and Gaposchkin:[4] RV Tauri stars are supergiants with (1) comparatively stable periodicity of light variation, whose amplitude may reach 3 magnitudes, (2) alternating shallow and deep minima, which occasionally interchange, (3) double-period of 30–150 days, and (4) F to K spectral class, which is earliest near maximum light. From the *GCVS* list we disregard those variables designated RV? and include only stars with periods in the range 39–110 days, since this is roughly the range of RV Tauri stars in globular clusters. Although some types of red variables in the same period range have light curves resembling those of RV Tauri stars, we assume that those variables without known spectra are yellow. In some cases photographic magnitudes were obtained from other sources.[4,6] Since the magnitude of CN Centauri is uncertain at minimum, it has been omitted from the distance determinations. Preston, Krzeminski, Smak, and Williams have shown that UU Herculis and V453 Ophiuchi are RV Tauri stars.[9] Apart from these two variables, their list of RV Tauri stars does not otherwise conflict with assignments given by the *GCVS*, in the period range 39-110 days. We have used their magnitudes and period for V 453 Ophiuchi. The total number of variables whose distances we may determine is 45, of which 25 have known spectra.

Preston *et al.*[9] have defined three groups of RV Tauri stars on spectroscopic criteria: A.—All spectral features indicate type G or K, except that TiO bands may occur during deep light minima. B.—The type based on the Ca II lines differs from that based on the hydrogen lines; strong CN bands occur at and around light minima. C.—The spectrum resembles that of group B, except that CN bands never appear. Moreover, the stars in group A are redder than those in groups B and C (which cannot be distinguished photometrically). The RV Tauri stars may be distinguished from the yellow semiregulars on the basis of *U,B,V* colors and strength of hydrogen emission. At the end of this paper we shall comment on these subdivisions.

The distribution of RV Tauri stars in longitude is far from scraggly, contrary to the results indicated by the smaller number of stars used in earlier investigations.[7] Indeed, Figure 1

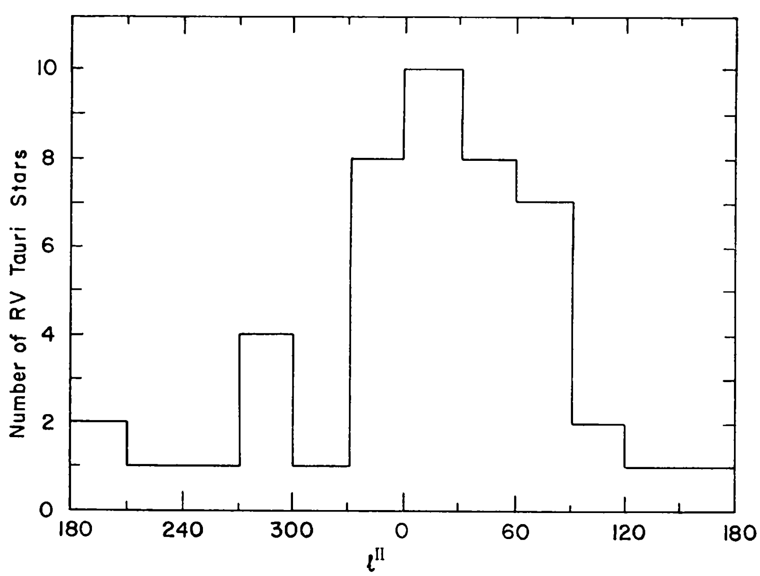

FIG. 1—Frequency distribution of the field RV Tauri stars in longitude.

shows a strong concentration of stars in the direction of the galactic center. Their spatial concentration depends on a knowledge of distances, which we may obtain from globular clusters.

In general, RV Tauri stars in globular clusters are specified by the same criteria as those in the field. Small deviations from these criteria have been discussed by Rosino[5] and Joy.[6] Other differences will be pointed out below. Using the mean photographic magnitudes of the nine certain RV Tauri stars in clusters (from the writer's previous paper,[10] hereafter called Paper I), we may obtain a period-luminosity relation, if the distance moduli of the clusters are known. We take the moduli from Hogg's list,[11] where she assumed that $M_{pg} = 0.0$ for the RR Lyrae stars. For M 2, M 5, and M 13, we have used the values of M_v of the RR Lyrae stars corrected for reddening listed by Arp[12] and have added C.I. $= +0.1$. For M 22, which closely resembles M 13,[13,14] and for ω Centauri, which has a main sequence turnoff at the same magnitude as M 3[15] (also listed by Arp), we assume analogous values of M_{pg}. For M 56 and NGC 6712 we adopt the mean of all the known values, $M_{pg} = +0.3$. Applying these corrections to Hogg's distance moduli, we obtain absolute magnitudes of the cluster RV Tauri stars. The period-luminosity relation is then $\langle M_{pg} \rangle = -4.0 + 0.026P \pm 0.36$, where P is in days, in reasonable agreement with previous determinations which depended on indirect or statistical methods.[5,6,7,17,18,19,20,21]

To calculate the distances of the RV Tauri stars in the field, we use

$$\langle M_{pg} \rangle = \langle m_{pg} \rangle - 10 - 5 \log r - a$$

where r is in kpc and $a = 0.7r$ if $|b^{\mathrm{II}}| < 20°$ or $0.25 \csc |b^{\mathrm{II}}|$ if $|b^{\mathrm{II}}| > 20°$. The first formula for extinction is used by Payne-Gaposchkin[16] and also happens to be the mean of extinctions derived for five RV Tauri stars by Kameny.[7]

Figure 2 shows the RV Tauri stars projected on the galactic plane. Variables with known spectra are indicated by open circles, those with unknown spectra by filled circles; the crosses denote the positions of the sun and the galactic center. It is difficult to corroborate the previously suspected[7] groupings

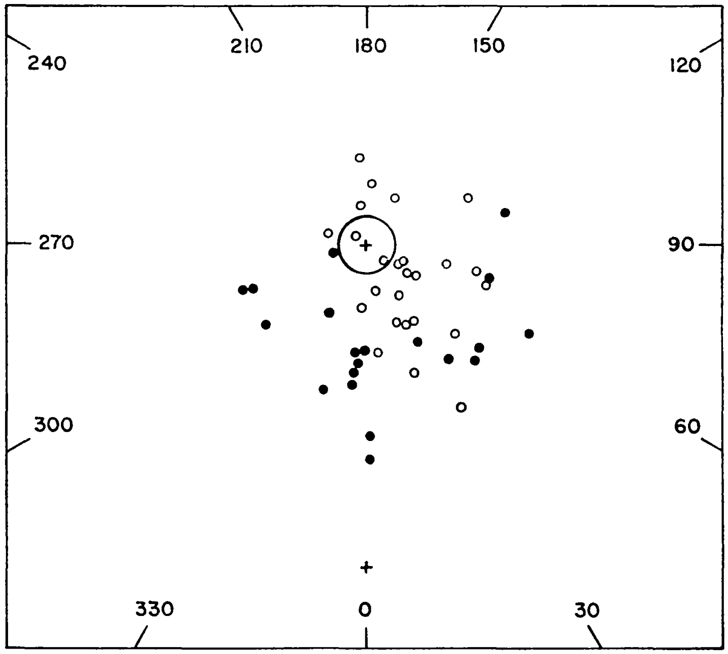

FIG. 2.—Field RV Tauri stars with known spectra (open circles) and unknown spectra (filled circles) are projected on the galactic plane. The positions of the sun and galactic center are denoted by + signs. The circle around the sun has a radius of 1 kpc.

near Ophiuchus (30°), Aquila (40°), and Gemini (180°), on the meager data available and the uncertain extinction. Other clumpings at 60° and 75° are also suspect, although the Sagittarius group (0°) is probably real. There is no apparent correlation of period with position in the Galaxy.

Figure 3 shows a vertical cross-section of the Galaxy, where the sun is assumed to lie at 10 kpc from the galactic center. As indicated also by Figures 1 and 2, the number of variables increases in the direction of the galactic center. Their apparent absence at low galactic heights is due to interstellar extinction. The distribution strongly resembles that of the long-period variables with $P < 250$ days, that is, intermediate between the distribution of long-period variables with $P > 250$ days (Population I) and the distribution of the halo RR Lyrae stars (Population II).[16] The vertical density gradient y, where log $N = x - y\ (r \sin b)$ and N is the relative number of stars, is 1.1, and the median height $\overline{r \sin b}$ is 0.45 kpc. Both these

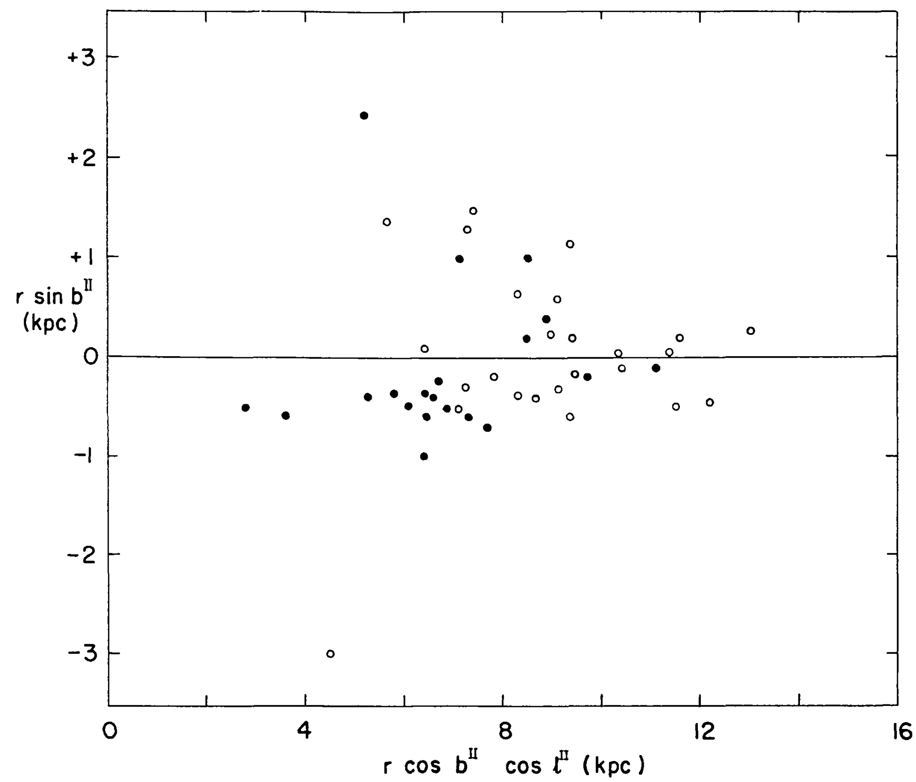

FIG. 3.—Vertical cross-section of the Galaxy, showing the distribution of field RV Tauri stars on the assumption that the sun lies at 10 kpc from the galactic center. Same symbols as in Figure 2.

quantities are similar to those for the long-period variables with $P < 250$ days.

Perepelkina suspected that the RV Tauri stars form an intermediate subsystem.[17] Their relatively low radial velocities and latitudes indicate a weak Population I, but their excessive blueness (like the W Virginis stars) and discontinuous velocity curves indicate Population II.[7] The yellow semiregulars, however, seem to be real Population II objects.

The general similarity of the RV Tauri stars in globular clusters to those in the field and the approximately equal ratios of number of RV Tauri stars to number of RR Lyrae stars[7] indicate that field and cluster RV Tauri stars belong to the same family. At maximum light the RV Tauri stars are usually the brightest cluster members and are found close to the cluster center (compared with the long-period variables).[10] Therefore, because of the long relaxation times of globular clusters, it seems unlikely that the RV Tauri stars in the field have evaporated from clusters, even apart from the observation that they do not form a halo population.

Besides their spatial distribution, some other differences between the field and cluster variables should be mentioned. While Rosino found no period-spectrum relation for the variables in the field,[5] Paper I showed such a relation for the cluster variables, although the stars seem to be separated chiefly into a 60- and a 90-day group. Kameny[7] found that the short-period RV Tauri stars in the clusters were slightly bluer than those in the field. No very long-period RV Tauri stars have yet been identified in globular clusters. Moreover, in the clusters there is a marked absence of RV Tauri stars in the period range 68–87 days. We note in Table I an actual anticorrelation of period frequency with the corresponding field variables. Lastly,

TABLE I

Period Frequencies of the RV Tauri Stars

P	Globular Clusters		Field	
(days)	RV	All Variables	RV (with Sp.)	RV (all)
28-47	0	1	3	5
48-67	5	7	6	15
68-87	0	2	15	23
88-107	4	13	3	5
>107	0	16	5	24

we mention that no RV Tauri stars in globular clusters have light amplitudes exceeding 2 magnitudes, whereas about one-third of the field stars in the same period range have greater amplitudes. All these differences may be due to different ages and chemical compositions.

The results of work by Preston *et al.*[9] indicate that, at least spectroscopically, the RV Tauri stars do not comprise a homogeneous class. Their group A of these stars shows TiO at minimum and resembles kinematically an intermediate (disk) population.[6] Group B is probably also related kinematically to the disk, and we note that it, too, shows the presence of metals in the strong CN bands. The radial velocities of group C stars are very high and suggest a halo population; the absence of CN is also suggestive. We note that the two variables from globular clusters that Preston *et al.* studied probably belong to the "halo" group C; it is interesting that, whereas groups A and B show a wide range in period, the three field variables from group C have periods lying in the "forbidden" range of the clusters.

If the RV Tauri stars plotted on the vertical cross-section of the Galaxy (Fig. 3) are distinguished according to groups, then it appears that groups B and C adhere very well to the above galactic assignments, whereas group A populates both the disk and the halo. However, it is clear that RV Tauri stars do not really range far enough to separate groups into halo and disk populations. Therefore the suggestion by Preston *et al.* that groups B and C belong to a larger family raises the further speculation that all the groups form really one family. At least this has been indicated by previous work.

In this connection, we note that there is no apparent relation between spectroscopic criteria and shape of light curve or period. Moreover, the colors appear to form a continuous sequence, despite the spectroscopic differences. Although Preston *et al.* could not obtain reliable luminosity classes at the dispersion they used, Rosino's data[5] suggest that the luminosity class falls with increasing period, in agreement with the results on variables in globular clusters.[10] Comparison of the general period-luminosity relations for the variables in globular clusters and those in the field suggests that any difference in the luminosity between the cluster and field RV Tauri stars does not exceed 1 mag. (Paper I, Fig. 11). We believe that the statistical identification of luminosities in the clusters and in the field is sufficient to outline the general spatial distribution of RV Tauri stars, as considered in this paper.

In conclusion, the RV Tauri stars seem to form an intermediate subsystem between Population I and II. Except for the underabundance of metals and the period-frequency anomaly, the RV Tauri stars in globular clusters resemble their counterparts in the field. Perhaps long-period variables in clusters with late integrated spectra should be investigated for RV Tauri behavior; in this connection we note the 105-day variable in NGC 6712 (G4). Certainly the known semiregular and irregular variables with undetermined periods should be checked for periods in the range 68–87 days.

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[1] H. Ludendorff, *A.N.,* **214,** 217, 1921.

[2] H. Ludendorff, in *Handbuch der Astrophysik,* Vol. 6, G. Eberhard, A. Kohlschütter, and H. Ludendorff, eds. (Berlin: Springer 1928), p. 174.

[3] B. P. Gerasimovič, *Harvard Obs. Circ.* No. 341, 1929.

[4] C. H. Payne-Gaposchkin, V. K. Brenton, and S. Gaposchkin, *Harvard Obs. Ann.,* **113,** 1, 1943.

[5] L. Rosino, *Ap. J.,* **113,** 60, 1951.

[6] A. H. Joy, *Ap. J.,* **115,** 25, 1952.

[7] F. E. Kameny, Dissertation, Harvard University, 1956.

[8] B. V. Kukarkin, P. P. Parenago, Yu. I. Efremov, and P. N. Kholopov, *General Catalogue of Variable Stars* (Moscow: Academy of Sciences, U.S.S.R. Press, 1958).

[9] G. W. Preston, W. Krzeminski, J. Smak, and J. A. Williams, *Ap. J.,* **137,** 401, 1963.

[10] R. Stothers, *A. J.,* **68,** 242, 1963.

[11] H. S. Hogg, in *Handbuch der Physik,* Vol. 53, S. Flügge, ed. (Berlin: Springer 1959), p. 129.

[12] H. Arp, *Ap. J.,* **135,** 971, 1962.

[13] H. C. Arp and W. G. Melbourne, *A. J.,* **64,** 28, 1959.

[14] A. Sandage and G. Wallerstein, *Ap. J.,* **131,** 598, 1960.

[15] E. P. Belserene, *A. J.,* **64,** 58, 1959.

[16] C. H. Payne-Gaposchkin, *Variable Stars and Galactic Structure* (London: Athlone Press, 1954).

[17] E. D. Perepelkina, *Perem. Zvezdy (Variable Stars),* **7,** 230, 1950.

[18] P. P. Parenago, *Astr. Zhurnal U.S.S.R.,* **11,** 95, 1934.

[19] A. H. Joy, *Pub. A. S. P.,* **46,** 51, 1934.

[20] W. S. Adams, A. H. Joy, M. L. Humason, and A. M. Brayton, *Ap. J.,* **81,** 187, 1935.

[21] D. McLaughlin, *Pub. Michigan Obs.,* **7,** 57, 1938.